International Journal of Scientific Research and Engineering Development-– Volume 6 Issue 2, Mar-Apr 2023

Available at www.ijsred.com

RESEARCH ARTICLE OPEN ACCESS

NPK 17-17-17– Biochar–Compost Tea –Co-Composted Tea Biochar Interactions on the Yield of Four Cassava Genotypes in Lubuya Bera in the Tshopo Province in the Democratic Republic of Congo

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Abstract:

Cassava is the first food and low cost resource in the D.R.Congo and in the province of Tshopo and constitutes a source of income for the majority of the Congolese populations.

The effects of the second green revolution translate the use of large quantities of chemical fertilizers imputs to increase agricultural production output [1]. This farming system is a source of pollution [2].

Climate-resilient agriculture leds to a third green revolution with the lever of the integrated use of organic amendments [3] such as Co – Composted Tea Biochar (CCBT) in order to sustainably increase agricultural production [4] in sandy-textured, nutrient-poor soils under drought conditions [5, 6,7] respecting the environment [8].

This study proposes to substitute totally or partially NPK 17-17-17 by biofertilizers and to test the performance of four cassava cultivars with respect to the different intakes of these fertilizers applied alone or in combination.

The device adopted is a 6 x 4 bifactorial with split plot into 4 repetitions,: (i): Fertilizers comprising 6 treatments which are T_0: Control; T_1: NPK fertilizer 17-17-17 applied alone; T_2: Biochar applied alone; T_3: Biochar combined with NPK 17 -17-17 ; T_4: Compost Tea; T_5: Co-Composted Tea Biochar and, (ii) Cassava cultivars (4 varieties; V_1: Liyayi (MM96/0287); V_2: Obama (TME 419); V_3: Zizila (MVZ99/038); V_4: Kindisa (I2006/1661).The device adopted is a 6 x 4.

Comparing root yield of the cassava varieties, we obtained respectively averages of 32.59 t. ha^{-1}, 39.75 t. ha^{-1}, 41.09 t. ha^{-1} and 49.39 t. ha^{-1} respectively for Kindisa, TME 419, Liyayi and Zizila against 22.80 t.ha^{-1}, 21.33 t.ha^{-1}, 22.85 t.ha^{-1}, 20.10 t.ha^{-1} for the control.

The inputs of fertilizers gave average yields estimated at 21.77 t. ha^{-1} for the control; 35.92 t.ha^{-1} for the Biochar brought alone; 39.15 t.ha^{-1} for the Biochar associated with NPK 17-17-17; 41.49 t.ha^{-1} when the compost tea is brought alone; 43.08 t.ha^{-1} for Biochar + Compost tea; 43.89 t.ha^{-1} for NPK 17-17-17 applied alone.

The Benefit/Cost ratio is 6.2; 5.6; 3.5; 3.0 and 6.7 respectively when the NPK 17-17-17 is brought alone; for Biochar applied alone; Biochar + NPK 17-17-17; compost tea brought alone and for the association Biochar + Compost Tea.

Keywords **— NPK 17-17-17, Biochar, Compost Tea, Co - Composted Tea Biochar.**

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I. INTRODUCTION

Dependence on food imports [9] on the one hand and an economy based on mineral resources [10] on the other hand remain major challenges in the Democratic Republic of Congo and make it possible to get the majority of households in the country out of food insecurity and chronic poverty that characterizes them. To overcome these constraints, a holistic approach based on the identification and prioritization of factors having a considerable ripple effect is essential.

In the context of population growth and climate change, maintaining food security is a major challenge for the rural populations of Lubuya Bera, Tshopo Province in the Democratic Republic of Congo. Meeting this challenge requires increasing food production through quality seeds [11] and integrated soil fertility management such as Co-Composted Tea Biochar (CCTB). The application of Co-Composted Tea Biochar (BBCT) [12] due to its recalcitrance [13] to mineralization and the longevity of the residence time in the soil being measured in hundreds or even thousands of years [14], [15], [16], [17], [18], [19] has the advantage of allowing the retention and gradual release of nutrients over time in a single dose [20].

The biochar and compost, derived from organic waste, contribute to the circular economy, another issue of waste production [21].

This study aims to improve food security by implementing the following specific objectives: (i) use high-yielding cassava cultivars and (ii) combine appropriate cultivation practices aimed at integrated soil fertility management.

The expected results will contribute to the practice of Climate – resilient Agriculture based on the use of less expensive biofertilizers, with lasting effects and after effects such as Co – Composted Tea Biochar (CCTB) [22].

II. STUDY AREA, MATERIALS, METHODS

A. STUDY AREA

Lubuya Bera (419 m Altitude, 00° 36' 30.6" N, 025° 10' 13.5" E) at kilometer point 12 on the Banalia road North of the City of Kisangani, of the Tshopo Province, in the North-Eastern part of the D.R. Congo was our study area.

1): CLIMATE

According to the classification of [23] we find in D.R.Congo the climate of the type A_f with the height of annual rainfall varying between 1600 and 1800 mm.

The average temperatures in Kisangani are generally constant throughout the year more or less 25°C. The highest temperatures are recorded between February and April and the lowest temperatures were obtained between the months of July and September with the monthly averages varying between 23.6°C and 24°C.The relative humidity fluctuates between 80 and 90%. Due to the high cloudiness of this region, insolation and radiation are low around 1925 hours or 45% [23].

The annual potential evapotranspiration is low and remains significantly lower than precipitation. Among the consequences of the abundance of rains, we must mention the intense alteration of the soil, the leaching of bases and the leaching of fine solid particles.

Estimates of climate data, including temperatures and rainfall, were obtained by cascading readings of the values entered in the geographical coordinates of the sites located using the geographical coordinates in LocClim Climate Estimator. The glass rain gauge and the digital thermometer were installed in the middle of each trial. The temperature data were taken every day 4 times a day, that is to say at 6 a.m., at 12 p.m., at 6 p.m. and at midnight. It was also every day that readings were taken on the rain gauge, taking care to empty the water after the reading.

Table 1. Climatic data during the experimental period (from February 05, 2021 to January 09, 2022).

	Average temperature (°C)	**Précipitations en mm**
Month		
February	26,5	50
March	26,2	101
April	26	200
May	25,7	195
June	25,5	125
July	25	50
August	24,7	100
September	24,6	200
October	25	230
November	25,1	210
December	25,2	165
January	25,4	80

2): SOIL

The soils of the experimental site correspond to Haplic Ferralsol (Dystric, Xanthic) according to [24]. Rich in iron and aluminum oxides, the soil of the experimental site is poor in humus. The texture is sandy-clay in the cultural profile (slice from 0 to 30 cm deep), while kaolinite is dominant in the fraction below 2µ. The apparent density at the start of the experiment was 1480 kg.m^{-3} and the hydraulic conductivity was 9,7.10^{-1}cm.hour^{-1}. The effective cation exchange capacity (CECE) was less than 10 C.mol^{+}.Kg^{-1} while the water pH was between 4 and 5.

3): VEGETATION

The original natural vegetation of Lubuya Bera is a dense rain forest. It is in the process of disappearing, giving way to various secondary formations of anthropic origin

Our experimental site was a five-year fallow established according to the order of dominance of the following species: *Chromolaena odorata*, *Imperata cylindrica*, *Hypparhenia rufa*, *Cynodon dactylon*, *Pteridium aquilinum*.

B. MATERIALS

The biological materials consisted of 4 cassava genotypes: Liyayi (low in beta-carotene), TME 419 (low in beta-carotene), Zizila (low in beta-carotene), Kindisa (rich in beta-carotene); 6 biofertilizers: NPK 17 - 17 - 17, biochar, lignin-rich and water-soluble materials while the non-biological materials concerned chemical reagents and microbiological products.

C. METHODS

For conditioning the biochar, we used moderate pyrolysis of dry common bamboo (*Bambusa vulgaris*) mixed with wet bamboo characterized by a temperature of around 500°C for 5 days. The coal thus obtained was crushed and sieved on the granulometric grid of 2 mm in diameter. The resulting powder was soaked to saturation for 24 hours with sodium hypochlorite (NaClO) solution diluted 4 times for chemical activation.

It was a question of increasing the adsorbent power of the biochar, in particular by eliminating the tars which clog the pores. The wort obtained was then dried in a muffle oven at a temperature of 800°C for 20 minutes. The resulting powder was washed several times and air dried.

The biochar obtained was enriched by saturation for 24 hours with the compost tea solution rich in microorganisms. Obtaining compost tea consisted of mixing raw compost and water (in a ratio of 1/10, weight/volume) in a fermenter under oxygen bubbling for 8 hours in order to boost the multiplication of microorganisms.

The determination of the pH at which the electric charge of Biochar is zero (pHpzc) was carried out according to the modified Boehm titration [26]. The determination of the acid functions (carboxylic acids, phenols and lactones) and basic functions (primary amines, secondary amines and protonable tertiary amines) of the biochar was carried out according to Boehm [26].

Regarding the adsorption capacity, we determined by titrimetry the iodine number. The iodine value is the amount in milligrams of iodine adsorbed per gram of biochar in an iodine solution. It characterizes the zones accessible to particles of a size greater than or equal to that of the iodine molecule, in particular the micropores.

The experiment ran from February 5, 2022 to January 9, 2023.

After clearing, the 100 m x 100 m plot was plowed flat to an average depth of 30 cm then divided into main plots and sub-plots according to the Split plot experimental device [27] with 4 repetitions. The land was divided into 4 blocks of 20 m x 20 m each. The blocks were 5 m apart. Each block was divided into 4 main plots of 20 m x 20 m separated by 5 m walkways. Each plot was subdivided into 6 secondary plots measuring 4 m x 3 m. The aisles between the secondary plots were 0.25 m.

The main factor Biofertilizers was placed in the sub-plots while the secondary factor variety was placed in the main plots. The 6 biofertilizers and the 4 genotypes were randomized in the main plots and in the sub-plots:

(i) 6 Biofertilizers; T_0: Control; T_1: NPK 17-17-17; T_2: Biochar; T_3: Biochar + NPK 17 -17-17; T_4: Compost Tea; T_5: Co – Composted Tea Biochar and

(ii) 4 Cultivars ; V_1: Liyayi; V_2: TME 419; V_3: Zizila; V_4: Kindisa.

The trial, comprising four replicates spaced 5 m apart, had 12 main plots and 24 secondary plots.

The biochar was buried at a depth of about 25 cm in the ground at a rate of 1 kg/pocket or 20 t/ha. The mini-cuttings with 4 cassava nodes were planted in a row in a lying position at spacings of 1 m x 1 m. The plants were thinned, thus reducing the population of plants to a density of 60 plants per plot, i.e. 60 x 24: 1 440 plants of all varieties combined.

Cultural care consisted of weeding, hoeing, hilling and topping every two months to promote branching, increase the photosynthetic table and the production of cassava tuberous roots.

The cassava harvest 12 months after planting consisted of uprooting 38 feet in each plot, excluding the border feet, ridding the tuberous roots of heavy soil particles and detaching them from the peduncles. The roots grouped according to the plots (varieties, treatments) where they were harvested, were weighed using a precision scale.

Soil samples were taken from each sub-plot using a soil probe 30 cm deep using the diagonal method. After drying in the open air in the shade, the individual samples were crushed and sieved on a 2 mm sieve, then mixed in equal proportions to form a composite sample per sub-plot.

The pH_{water} was measured by the electrometric method in a soil: water ratio of 1:2.5. The particle size analysis was determined by the pipette method; total organic carbon by wet process according to Walkey and Black [28], total nitrogen according to [29] after mineralization and assimilable phosphorus according to [30]. Acid cations (H^+ and Al^{3+}) were determined after extraction with AG – TU reagent according to [31] by titrimetry and exchangeable bases (Ca, Mg, K, Na) by atomic absorption spectrometry. The texture was determined using the pipette method.

With regard to the microbiological analyses, the soil samples at a rate of 2 g were taken at the level of the rhizosphere of the culture, at a depth of 15 cm. For the isolation of bacteria, we used 5 types of culture medium: (i) soil-based medium; (ii) nitrite broth; (iii) ammonium broth; (iv) medium based on mineral elements; (v) nutrient agar + ammonium; nutrient agar + nitrite; nutrient agar + nitrate

For the isolation of bacteria, we prepared 4 types of culture medium: (i) soil-based medium; (ii) nitrite broth; (iii) ammonium broth; (iv) medium based on mineral elements; (v) nutrient agar + ammonium; nutrient agar + nitrite; nutrient agar + nitrate.

For the purification of isolated bacteria, we used 3 media, namely: (i) nutrient broth + Agar + $(NH_4)_2SO_4$; (ii) nutrient broth + Agar + $NaNO_2$; (iii) nutrient broth + Agar + KNO_3 to promote the growth of nitrifying bacteria.

Ten typical colonies are isolated from each sample from the Petri dishes containing the medium and subcultured in the nitritive broth and incubated at 30°C. For Gram staining, the procedure is that of [32], [33].

The macroscopic identification elements are: (i) the shape of the colonies: round, irregular; (ii) the size of the colonies by measuring the diameter: pinctiform or non-pinctiform; (iii) chromogenesis: color of the colony; elevation: convex, concave, flat; (iv) opacity: opaque, translucent or transparent; (v) surface: smooth, rough, dry, jagged, etc.

The fermentation type test makes it possible to know the type of metabolism by which the substrate is transformed, and the production of gas from the reduction or oxidation of ammonia, nitrite and nitrate.

The response of the test plant, cassava, to the treatments applied was assessed by determining the number of plants harvested, the number of marketable roots, the number of unmarketable roots, the dry matter of the roots, the weight of the marketable fresh roots, the length of the roots, the root diameter, specific weight, starch content.

Using the 'Fieldbook' software previously programmed according to the experimental device of the test, the measurements and the counts carried out were recorded in the tablet having the program. This software minimizes careless errors that often occur when collecting data in the field.These data were then stripped and thanks to Fieldbook, they were organized for statistical analyzes in appropriate software.

Dry matter and starch analyzes were carried out on fresh plant tissues, mainly tuberous roots, and consisted of parboiling 105°C for 24 hours and root starch by specific gravity [34].

The raw results of the experimental treatments, the relationships between the edaphic and biological parameters on the one hand and the edaphic and biological parameters on the other hand were respectively compared and determined using the SPSS: 20.

The economic profitability of the study was evaluated by the Marginal Rate of Return (MRR) method in accordance with the recommendations of [35].

III. Results and Discussion.

A. Results

1): Chemical analysis of biochar

Increasing the pH of the soil to neutralize its acidity using limestone amendments such as lime is a costly operation and not economically justified for the small farmer. The thermochemical conversion of biomass during pyrolysis for the manufacture of biochar generates alkaline substances at low cost [36], [37], [38], [39], [40], [41], [42], [43]. The adsorption (Table 1) of phenolates, carboxylates and hydroxyls on biochar surfaces [43], [44] allows the soil have a net negative charge (pHpzc = 8) and allows it to bind to H^+ ions and retain more fertilizing elements [45].

Table I. SURFACE CHEMICAL CHARACTERISTICS of BIOCHAR.

	Biochar	Biochar enrichi
Total acid functions ($meq.g^{-1}$)	**2,48**	**4,68**
Carboxyl (-COOH)	0,86	1,55
Lactones (- C00-)	0,9	1,78
Phénol (- OH)	0,72	1,35
Total basic functions ($meq.g^{-1}$)	**0,64**	**1,03**
(Amines, - NH_2)	0,64	1,03
pH_{PZC}	8,01	8
CRE (%)	165,8	222,7
II ($mg.g^{-1}$)	875,3	

Legend.pH_{pzc}: zero charge point pH;CRE: Retention capacity;II: Iodine Index.

The total basic functions are essentially of the NH_3/NH_4^+ couple at a rate of 0.64 $meq.g^{-1}$ for the dry biochar and 1.03 $meq.g^{-1}$ for the Co – Composted Tea biochar.

At the zero point pH of 8, the biochar enriched of compost tea provides the soil with effective NH_3/NH_4^+ buffering capacity. The combined action of Nitrosomonas and *Nitrobacter* bacteria (Table II) cause the NH_3/NH_4^+ couple to be oxidized to nitrates (NO_3^-), a form of nitrogen available for crops.

The water holding capacity by dry biochar and compost tea impregnated biochar is respectively 165, 8 % et 222, 7 %.

This impact of biochar may not be substantial if either the biochar surface area or pore volume is low or the soil texture is fine, as in soils with higher clay content . A biochar with a high surface area and pore volume canbenefit soil water retention capacity in several ways: by reducing soil bulk density [46], increasing total average pore size [47] and the surface area of soil [48]. Optimizing biochar surface characteristics can maximize biochar's capacity to improve soil water retention [49].

Iodine adsorption accounts for the contribution of biochar in improving the hydraulic properties of sandy soils [50] and decreasing the bulk density of the soil. The latter facilitates aeration, infiltration and root penetration.

The retention capacity, iodine index variables take into account the porous character of the biochar at a rate of 165.8 meq/g, 227.7 meq/g and 875 meq/g respectively for the retention capacity of the biochar alone, the Co- Composted Tea Biochar retention capacity, the iodine value of biochar alone. Reference [51] found an iodine value of 190.21 mg. g-1 for rice straw against 846 mg. g-1 for seaweed in [52]; while [53] tested Algerian bentonite (Qmax = 118 mg·g-1) with a contact time of 3 h. Reference [54] found an average iodine value of 457.2 mg. g-1 for Phragmites. We can say that our bamboo-based biochar with an iodine value of 875.30 mg.g-1 has larger micropore surfaces. This can promote soil water saving and build resilience to climate change in the context of predominant rain-fed agriculture in Africa.

2): Bacterial characterization of Co – Composted Tea Biochar.

The surfaces and pores of the biochar serve as ecological niches [55], [56], [57], [58], [59] for the microbial biomass whose growth from different substrates such as litter and crop roots for its metabolism and improve the physico-chemical properties (raised pH, gritty structure, low bulk density, retention and hydraulic conductivity) allowing soils with a sandy texture to fight against water stress between rainfall events when the matrix potential increases [60], [61].

In general, cultivated soils located in the tropics are characterized by a low pH and a lack of organic matter. The elevation of soil pH by biochar on the one hand [62] and the addition of a microbial co-substrate on the other hand act on the C/N ratio of the soil, promote the abundance, activity of bacteria [63] and protection against degradation through the formation of stable aggregates [64].

Table II. BACTERIAL CHARACTERIZATION of CO - COMPOSTED TEA BIOCHAR.

Tt	Broth based on NH_4^+		Broth based on NO_2^-		Broth based on NO_3^-	
	NH_4^+	NO_2^-	NH_4^+	NO_2^-	NH_4^+	NO_2^-
T_0, T_1	Small Rod - shaped bacteria	Small Rod – shaped bacteria and chain – shaped bacteria	Rod – shaped bactéria	Small Rod – shaped bacteria and chain – shaped bacteria	Rod – shaped bactéria	Small Rod - shaped bacteria
T_2, T_3	Small Rod – shaped bacteria and chain – shaped bacteria	Small Rod – shaped bacteria and chain – shaped bacteria	Rod – shaped bactéria	Rod – shaped bactéria	Small Rod - shaped bacteria	Small Rod – shaped bacteria
T_4	Small Rod – shaped bacteria and chain – shaped bacteria	Small Rod - shaped bacteria	Small Rod – shaped and rounded bacteria	Small Rod - shaped bacteria	bacteria in the shape of a small rod, rounded and pointed	Small Rod – shaped and rounded bacteria
T_5	Small Rod – shaped and rounded bacteria	Small Rod - shaped bacteria	Small Rod – shaped and rounded bacteria	Small Rod - shaped bacteria	Small Rod – shaped and rounded bacteria	Small Rod – shaped and rounded bacteria

The analysis of Table III shows that the colonies of bacteria isolated from the soil for different treatments and broths are predominantly Gram negative with 18 out of 30 present, i.e. a Gram negative/Gram positive ratio of 3/2. The T_4 and T_5

treatments showed the presence of both Gram-positive and Gram-negative bacteria.

Table III. GRAM STAIN of ISOLATED BACTERIA

Treatment	NH_4^+ broth		NO_2^- broth		NO_3^- broth	
	NH_4^+	**NO_2^-**	**NH_4^+**	**NO_2^-**	**NH_4^+**	**NO_2^-**
T_0, T_1	–	– et +	–	–	–	–
T_2, T_3	– et +	–	–	–	–	–
T_4	–* et +	– et +	– et +	–	– et +	–
T_5	– et +	–	– et +	–	–	– et +

Legend . **+** : Gram positive, – : Gram negative, –* : Abundant Gram negative.

3): Soil parameters.

Table IV. EFFECTS of TREATMENTS on SOIL PARAMETERS.

Traitements	T_0	T_1	T_2	T_3	T_4	T_5
pH_{eau}	4,6	4,6	7,6	8,1	7,9	9,3
Org C (%)	0,725	1,6	22,3	23,7	21,8	24,3
Total N (%)	0,062	0,08	0,8	0,9	2,4	2,9
C/N	11,7	20	27,8	26,33	9,08	8,4
Ass P (mg. kg^{-1})	8,02	20,8	22,33	24,9	44,6	65,15
Exch Ca (c.mol $^+kg^{-1}$)	0,61	0,67	0,74	12,9	19,68	30,1
Exch Mg (c.mol $^+kg^{-1}$)	0,06	0,07	0,08	10,75	22,01	33,66
Exch K (c.mol $^+kg^{-1}$)	0,18	14,5	14,8	14,85	12,8	15,22
Exch Na (c.mol $^+kg^{-1}$)	0,05	1,57	1,61	1,85	1,96	2,08
Exch H (c.mol $^+kg^{-1}$)	0,75	0,69	0,41	0,27	0,12	0,08
Exch Al (c.mol $^+kg^{-1}$)	0,68	0,61	0,15	0,11	0,09	0,04
CEC (c.mol $^+kg^{-1}$)	10,35	38,91	40,12	65,63	101,26	146,33
Sand (%)	63	64	66	70	67	71
Silt (%)	27	24	22	24	12	12
Clay (%)	10	12	12	6	21	17
Texture (FAO)	LS	LS	LS	LS	LAS	LS

Legend. Org C : Organic Carbon ; Total N : Total Nitrogen ;
Ass P : Assimilable Phosphorus ;Exch Ca : Exchangeable Calcium ;
Exch Mg : Exchangeable Magnesium ; Exch K : Exchangeable Potassium ;
Exch Na : Exchangeable Sodium ; Exch H : Exchangeable Hydrogène ;
Exch Al : Exchangeable Aluminium ;
CEC : Cation Exchange Capacity ; LS : Limon Sable

Acidity, high levels of exchangeable aluminum, unavailability of soil phosphorus are among the main edaphic constraints of ferrallitic soils [65] very widespread in D.R.Congo.

The rational approach to remove these constraints involves the identification, the prioritization of pedogenetic factors with a significant ripple effect. These are mainly organic materials. Indeed, the decomposition of organic matter generates substances capable of immobilization the exchangeable Aluminum (Al^{3+}) stable soluble chelates which would be eliminated from the cultural profile by drainage, thus making available the phosphorus released from the fixation sites.

All treatments with exception of T_0 and T_1 significantly improved soil pH_{H2O}. Biochar with compost tea as a co-substrate with a pH of 9.3 performed best (exchangeable H^+: 0.08 $c.mol^+.kg^{-1}$; Al^{3+}exchangeable: 0.04 $c.mol^+.kg^{-1}$). sustainable cassava agriculture in particular. For T_5 (Organic carbon: 24.3%; Total nitrogen: 2.9%; C/N: 8.4; Cation exchange capacity: 146.33 $c.mol^+ .kg^{-1}$; assimilable phosphorus: 65,15 $mg.kg^{-1}$), organic matter contributes from a physical point of view to improving the structure of a sandy-textured ferralsol (FAO Texture: LS).

4) : Yield components of cassava roots

TABLE V. RESPONSE of THE CASSAVA to THE TREATMENTS APPLIED

Var	**Tt**	**NMR**	**WRM (kg)**	**RL (cm)**	**RD(cm)**	**RDM (%)**	**RSC (%)**	**Yied ($t.ha^{-1}$)**
V1	T0	36,66	47,47	28,30	6,06	32,74	17,34	22,85
V1	T1	24,00	50,55	31,20	5,90	32,97	17,50	41,28
V1	T2	90,33	157,11	34,73	6,33	32,76	17,35	44,18
V1	T3	89,33	124,51	29,76	6,46	35,94	19,61	36,96
V1	T4	67,66	246,56	32,16	6,36	32,98	17,51	**46,19**
V1	T5	79,33	126,32	31,30	5,93	32,78	17,37	36,84
V2	T0	73,00	42,47	36,43	4,86	33,14	17,62	21,33

V2	T1	122,66	62,57	36,26	4,83	34,33	18,47	40,93
V2	T2	59,33	28,50	36,10	4,80	35,70	19,44	33,07
V2	T3	134,00	201,50	36,43	5,03	36,35	19,90	**49,74**
V2	T4	90,66	126,09	36,73	5,06	36,85	20,25	35,56
V2	T5	118,66	177,10	**38,83**	5,10	35,91	19,58	39,46
V3	T0	42,00	32,63	31,73	5,54	33,33	17,76	20,10
V3	T1	66,00	142,21	33,86	5,76	34,45	18,55	**57,39**
V3	T2	67,66	39,47	31,40	5,21	34,42	18,53	40,15
V3	T3	60,33	155,79	35,96	5,83	35,26	19,12	46,39
V3	T4	74,66	158,80	35,63	5,36	34,46	18,56	54,63
V3	T5	71,00	147,42	32,10	5,24	35,43	19,25	48,39
V4	T0	47,33	42,95	29,30	6,20	28,40	14,27	22,83
V4	T1	65,66	156,78	28,66	5,86	29,42	14,99	35,99
V4	T2	70,00	165,05	33,10	6,70	31,95	16,78	26,69
V4	T3	56,33	**353,34**	23,30	**6,90**	28,55	14,37	23,50
V4	T4	58,66	81,20	27,068	6,80	26,67	13,04	29,59
V4	T5	**141,33**	314,72	27,20	6,56	27,99	13,98	**47,61**

Legend.NMR: Number of marketable roots;
WRM: Weight of marketable roots;
RL: Roots length
RD: Roots diameter
RDM: Roots Dry Matter
RSC: Roots starch content

Table V reveals significant differences between varieties and treatments. The biochar treatment enriched with compost tea under the Zizila cultivar gave significantly efficient yields at the 1% threshold of the order of 57.39 t.ha-1.

The discrimination of varieties and treatments shows for the cultivar Liyayi a significant correlation ($p < 0.05$) in the Pearson test between yield and the weight of marketable roots (r = 0.575). After analysis, compost tea was the most efficient treatment (46.19 $t.ha^{-1}$). It would have facilitated the absorption of nutrients by the tuberous roots of cassava by the formation in the root profile of soluble and mobile chelates with acid cations, thus releasing potassium and phosphorus binding sites.

Compared to the TME 419 genotype, the treatment that acted significantly at the 0.01 threshold is biochar combined with mineral fertilizer 17-17-17 with an average yield of around 49.74 $t.ha^{-1}$.

The correlation analysis of the parameters at the threshold of 0.05 in the Pearson test reveals that the yield is influenced by the number of commercial roots (r = 0.575). The significant relationship between the number of marketable roots and the weight of the roots (r = 0.608) suggests that the treatment having acted effectively on the number of marketable roots indirectly influenced the yield. This is the biochar associated with the mineral fertilizer 17-17-17.

The response of the Zizila cultivar to the application of the treatments was more significant at $p < 0.05$ under the uncombined mineral fertilizer 17-17-17.

All treatments improved root yield of cassava under different genotypes. Indeed, the increase in yield compared to the control is 202% for the Liyayi variety for uncombined compost tea, 233% for the TME 419 variety under biochar biochar associated with mineral fertilizer 17-17 -17, by 285% for the Zizila cultivar under the uncombined 17-17-17 mineral fertilizer; 208% for the Kindisa variety under biochar with compost tea as a co-substrate according to the model shown in Figure 3. With regard to the Liyayi variety, a reduction in yield of around 86% is observed, 82% respectively when combining biochar with mineral fertilizer and biochar combined with compost tea compared to the average of the inputs taken individually. On the other hand, for the TME 419 variety, the ratio of the combination of Biochar and the average of the inputs taken individually is 1.34 and 1.15

respectively under the biochar associated with mineral fertilizer and the biochar associated with compost tea. For the Zizila genotypes, the increase in yields under mineral and organic combinations is 48% and 2% respectively. For the Kindisa variety, the decrease compared to mineral fertilizer is 25% against an increase of 69%for the organic combination. It can be said that organic fertilizer alone or combined with positive after effects can replace mineral fertilizer under the conditions of our experiment.

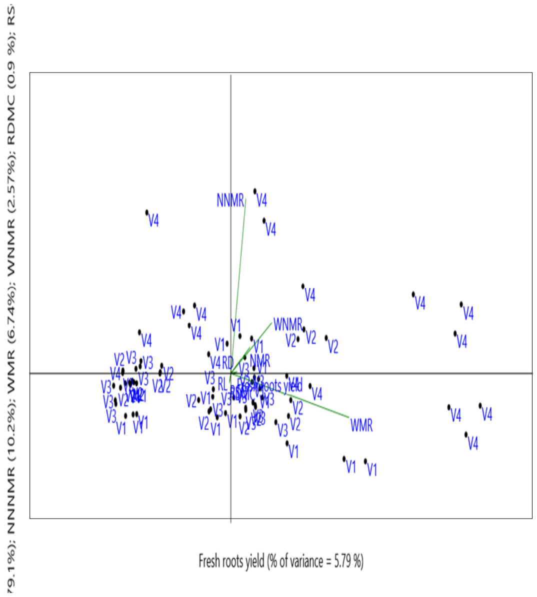

Figure 5. PCA Biplot of cassava NMR,, WMR, RDMC, RSC, RL, RD. V_1; V_2; V_3; V_4.

Legend:

NMR: Number of marketable roots

WMR: Weight of marketable roots

RDMC: Roots dry matter content

RSC: Roots starch content

RL: Roots length
RD: Roots diameter
V_1: Variety Liyayi;
V_2: Variety TME 419;
V_3: Variety Zizila;
V_4: Variety Kindisa

Figure 7. Size of the Liyayi cultivar

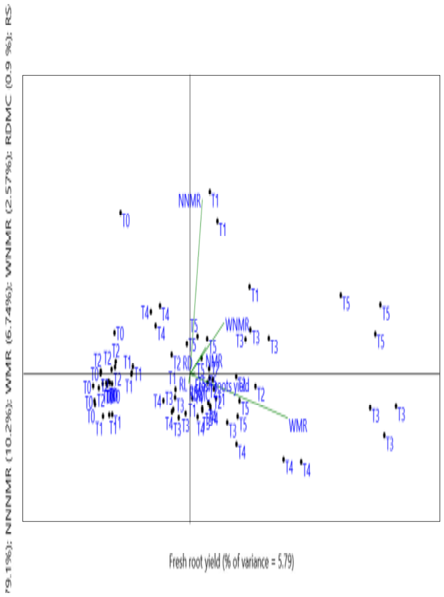

Figure 6. PCA Biplot of cassava NMR, WMR, RDMC, RSC, RL, RD; FRH.T_0; T_1; T_2; T_3; T_4; T_5.

Legend:

NMR: Number of marketable roots

WMR: Weight of marketable roots

RSC: Root starch content

RL: Root length

RD: Root diameter
FRY: Fresh root yield
T_0: Control
T_1: NPK 17-17-17
T_2: Biochar
T_3: Biochar + NPK 17 -17-17
T_4: Compost tea
T_5: Biochar + Compost tea

Figure 8. Size of the TME 419 cultivar

Figure 9. Size of the Zizila cultivar

Figure 10. Size of the Kindisa cultivar

Table VI reveals in a context of climate change and galloping population growth that cassava cultivation is profitable in the Kisangani region. ton of fresh roots. All treatments under all genotypes were shown to be cost-effective. The value/cost ratio is 6.7; 6.2; 5.6; 3.5; 3.0 respectively for T_5; T_1; T_2; T_3 and T_4.

TABLE VI. EFFECTS of TREATMENTS on the FINANCIAL PROFITABILITY of CASSAVA ROOTS.

	T_0	T_1	T_2	T_3	T_4	T_5
Total Cost (US$)	758	1468	1257.5	1735	1320	1390
Marginal Cost (US$)	-	710	499.5	977	562	632
Yield (t. ha^{-1})	21.77	43.89	35.92	39.15	41.49	43.08
Δ Yield (t. ha^{-1})	-	22.12	14.15	17.38	19.72	21.31
Value Δ Yield (US$)	-	4,424	2,830	3,476	3,944	4,262
Ratio Value/Cost (RVC)	-	**6.2**	**5.6**	**3.5**	**3.0**	**6.7**

B. Discussion

1) : Chemical characterization of biochar

The results of the Boehm titration of Co-Composted Biochar are 4.68 meq.g-1 of total acids, 1.03 meq.g-1 for surface basic functions and pHpzc of 8.0. In an activated carbon assay, [66] found total surface oxygen groups of 4.39 meq.g-1, total basic groups of 2.25 meq.g-1 and a pHpzc of 8.48.

The pH (7.59) found by [67] in Co - Composted Biochar is lower than those found by [51] i.e. 10.02 in Biochar derived from Apple tree branch; 9.68 in Biochar derived from oak tree; 9.62 in Biochar derived from rice husk and 10.47 in Biochar derived from rice straw. In an assay on Biochars deriving from Orange Peel Biochar and Green Coconut Shell Biochar, [45] found pH values of 8.78 and 8.41 respectively against a pH variation of 9.19 to 11.20 on different samples [68]. [69] found pH of 9,78 on Biochar derived from Palm Kernel Shell. Biochar is therefore a low-cost calcareous soil amendment for acidic soils [70].

In a study on activated carbon, [66] revealed a pH_{pzc} of 8.40 attributed to the presence of a high content of carboxylic groups on its surface.

The surface acid functions provide information on the adsorption capacity of nutritive or toxic mineral elements. Qualitatively, the acidic and basic groups were highlighted by instrumental methods [71, 72, 73, 74, 75, 76, 77, 78, 79]. Carboxylic acids provide biochar with intense surface activity such as buffering, catalysis for organic synthesis for microbial metabolism [80, 81, 82, 83, 66, 83] .

Instrumental analysis reveals the presence of basic surface functional groups coexisting with the acid groups of surface conferring on this environment the role of donors and acceptors of electrons [84].

Quantitatively, compared to biochar alone, this capacity increased in enriched biochar by 88.71% compared to 1–11% and 7.4–38.8% respectively for aged bush biochar and aged peanut shell biochar [85].

2): Microbiological characterization of biochar

The reactivity of biochar surfaces to organic compounds promotes soil enzymatic activity [13], [38], [58], [83] and [84] and facilitates nitrogen fixation by rhizobia [86], [87]. Nevertheless [4], [72], [73] observed the reduction of the activities of dehydrogenases and esterases thus inhibiting the absorption of substrates. The Gram +/Gram - bacteria ratio is favored by the burial of the biochar in the soil. Based on morphological identification, out of around thirty isolates, 18 are gram-negative colonies and correspond to the genus Nitrosomonas and Azotobacter (T_4 and T_5) and Nitrobacter (T_0, T_1, T_2), 10 chain isolates are Gram-positive.

Contrary to [88], despite the unfavorable physicochemical characteristics of the environment (acid pH), we noticed the preponderance of the genus *Nitrobacter* which, in the absence of nitrite (NO_2^-), oxidizes the ammonium ion (NH_4^+) to nitrate (NO_3^-) which is the form of nitrogen valued by the crop but not available in our condition due to leaching.

The presence of the *Azotobacter* and *Nitrosomonas* genera under T_5 reflects the reducing and oxidizing activity of these microorganisms in the nitrogen cycle. The reduction of atmospheric nitrogen, N_2 to ammonium ion (NH_4^+) by *Azotobacter* is followed by the reduction of the latter adsorbed to nitrate (NO_3^-) as described by [89]. The nitrate which is available for cultivation in a basic medium thanks to the contribution of Co-Composted Tea Biochar.

Our results are close to those obtained by [90]; who isolated and characterized developmental promoter bacteria (PGPB) associated with chickpea (*Cicer arietinum L.*). These results show that the selected nitrogen-fixing isolates are rounded, motile, Gram-negative, catalase- and oxidase-positive, strict aerobic bacilli. phenotypic observation and biochemical identification of the selected nitrogen-fixing isolates showed that they belonged to the genus Azotobacter and Nitrobacter [91].

3) : Edaphic characterization for different treatments.

Reference [93] report the effects of biochar on increasing organic carbon levels, cation exchange capacity as well as improving the availability of assimilable phosphorus, potassium, exchangeable calcium and magnesium. In our study the same trend was observed with the decrease of exchangeable H^+ and Al^{3+} in acid ferralsols with sandy texture.

Unlike [94] and [95] with the exception of T_1, the pH in our trial increased after compost tea application and co-application of biochar.

The saturation rate in exchangeable bases adsorbed on the surfaces of the biochars is 99.92% against 0.08% which is the saturation rate of the acid cations also adsorbed on the surfaces of the biochars. In an environment dominated by colloids with variable charge, the rise in pH combined with the chelation of acid cations leads to an increase in the cation exchange capacity of colloids dominated by exchangeable bases including exchangeable K^+ [96],[97].

4): Components of cassava root yield for different treatments.

From the principal component analysis making it possible to verify the interdependence of different variables with respect to the yield and the analysis of the trend lines by biplot, we observe the following:

With regard to the cassava varieties compared (Figure 5), the Kindisa variety (V_4) indicates a trend of the points furthest from the yield line. This variety has been the most productive with regard to the treatments applied to cassava varieties. In contrast, it is the varieties zizila (V_3) Liyayi (V_1) and TME (V_2) that achieve less production compared to the treatments applied. Moreover, Zizila produced more marketable roots while Kindisa's roots were the smallest and therefore not marketable.

The combination of Biochar with mineral fertilizer (T_3) and the combination of biochar with compost tea (T_5) gave very efficient values. The yields of cassava in fresh roots are relatively good when the compost tea is brought alone. This treatment brings an advantage by the fact that it makes it possible to obtain the greatest weight of marketable roots. T_3 and T_5 although they improve the production yield of fresh roots, they produce a higher weight of non-marketable roots. The control (T_0) is less efficient clearly demonstrating the need to carry out the inputs of fertilizers. In the same way, when the NPK 17-17-17 (T_1) fertilizer is added alone, it ensures very small increases in cassava yield. An important reason to substitute it for biofertilizers or combine it with biochar (T_3) to make it quite effective and likely to significantly increase the yield of cassava.

For [103] despite the plasticity of cassava cultivation on marginal soils, chemical fertilizers can significantly increase root yield. Nevertheless [104], [105] inform that the acquisition of fertilizers in Kisangani is difficult and expensive. It is therefore not within the reach of farmers. Unlike [100], application of Co-Composted Tea Biochar (CCTB) gave yields of 36.84; 39.46; 48.39; 47.61 $t.ha^{-1}$ against for NPK 17 - 17 - 17 22.85; 21.33; 20.10; 22.83 $t.ha^{-1}$ respectively for Liyayi varieties; TME 419; Zizila and Kindisa. The after-effects of Co-Composted Tea Biochar suggest ever-increasing production over a longer period of time.

5): Financial profitability

The structure analysis of costs (incorporating transport, mechanical tillage and pesticides) and benefits by [101] in the Ashanti region of Ghana showed a relatively low rate of return of 1.06.

The inputs representing the costs of cassava production in the Ogun State of Nigeria were mechanical tillage, chemical fertilizers and labour. They represented in relation to the profit a rate of 44% [102].

The inputs representing the costs of cassava production in the Delta region of Nigeria were mechanical tillage, chemical fertilizers and labour. They represented in relation to the profit a rate of 44% against a Marginal Rate of Return of 3.22 [103].

Assessing the profitability of cassava in the Delta region of Nigeria [104] found an overall profit margin of 1.93, with significant differences between regions as well as farm size categories.

Reference [105] finds a relatively low financial rate of return for cassava of around 1.39. The operating costs with these applications are low and the income is relatively large. However, current generally empirical practices are irrational and do not generate a benefit.

The Marginal Revenue Rate under T_5 (6.7) being close to that under T_1 (6.2), the after-effects of Co - Composted Tea Biochar buried in a single dose unlike mineral fertilizer spread by fraction at each cropping season will induce over time a more abundant production and a higher RBC.

The financial profit generated can be invested in the development of value chains involving technologies for the conservation, processing and partial or total incorporation of cassava bread flour in the preparation of bread, the import of wheat flour having become problematic since Russia's war against Ukraine.

IV. Conclusion

Surface chemical characteristics (FA = 4.68 meq.g-1; FB = 1.03 meq.g-1; pHpzc = 8; CRE = 222.7%; II = 875.3 mg.g-1) give biochar enriched with compost tea interesting colloidal properties as a regulator of soil reaction, adsorbing organic anions including assimilable phosphorus (15.1 mg. kg-1), chelating agent for toxic acid cations and ecological niche (II = 875.3 mg.g-1) by these micropores to Gram-negative bacteria corresponding to the genera Nitrosomonas, Azotobacter and Nitrobacter, molecular nitrogen-fixing bacteria.

The porous structure, the high specific surface highlighted by the iodine index of 875.30 mg.g-1 is likely to increase the affinity of the biochar for charged particles and soil water thus contributing to resilience in a context of climate change. The effects and after-effects of biochar enriched with compost tea induce increases in grain maize yield of around 210% compared to the control.

The adsorption of water and nutrients on the one hand and the presence of microorganisms in the pores of the biochar on the other hand will generate ever-increasing yields over time in the context of climate-resilient agriculture.

The RVC of 6.7 suggests investment in compost tea-enriched biochar production and cassava value chain technologies.

Acknowledgements

The authors thank to the technicians of the Soil Science laboratories of the University of Kisangani, of Microbiology and Organic Chemistry of the University of Kinshasa.

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Conflicts of Interest

The author declares no conflict of interest.